Bioengineering and Medical Informatics degree programmes in the European Union

Executive Summary

BioEMIS is a European Commission Tempus project to develop new study programmes in Bioengineering and Medical Informatics at universities in the West Balkans. This report summarises the work undertaken in work package 1.1 to analysis the Bioengineering and Medical Informatics degree programmes at universities in the European Union (EU). The work package included analyzing degree programmes at 221 European universities, spread over 30 countries. The resulting information will be used to inform the development of new study programmes in Bioengineering and Medical Informatics at universities in the West Balkans.

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1. Introduction

BioEMIS is a European Commission Tempus project to develop new study programmes in Bioengineering and Medical Informatics (BE&MI) at universities in the West Balkans (WB). This report summarises the work undertaken in work package 1.1 to analysis the Bioengineering and Medical Informatics degree programmes at universities in the European Union (EU).

In order to develop study programs in BE&MI at all three university levels in WB countries, the BioEMIS Tempus project team from University of Kragujevac (Serbia) conducted a thorough analysis of similar study programs offered in the EU. The objective of the analysis was to create the foundation for harmonized future inter-institutional cooperation, students' and faculty staff mobility, integrated programs of study, training, and research [1]. During the last decade, many papers have been published on this topic, but most of them considered the field of BE&MI at national level. For instance, Proceedings of the Institution of Mechanical Engineers, Part H: J. Engineering in Medicine dedicated their Volume 223(4) to Biomedical Engineering Education [2-9], as well as IEEE Engineering in Medicine and Biology Magazine - Volume 26, Issue 3 [1, 10-14], Annals of Biomedical Engineering - Vol. 34, No. 2 [15-24], IEEE Transactions on Biomedical Engineering [25-26], IEEE Reviews in Biomedical Engineering [27], IEEE Engineering in Medicine and Biology Society Conferences [28-31], Methods of Information in Medicine [32-35].

In addition, educational projects BIOMEDEA (2004) and Curricula Reformation and Harmonization in the field of Biomedical Engineering (Tempus - JP 144537-2008) brought significant advances in setting guidelines, standards and procedures for harmonization of education and generation of qualifications in BE&MI [1], [36-38].

2. Criteria of the analysis

The main objective of the analysis was to identify core courses that define the broad field of BE&MI, which will be the basis for study programs development. In order to achieve this different European study programs containing relevant courses were analyzed. It should be noted that although the mainstream in this area is to develop integrated BE&MI study programs, many universities still tend to offer these study programs within other ones, e.g. engineering study programs. This analysis is based on:

1) Core BE & MI study programs
2) Variety of study programs that contain BE & MI related disciplines/courses
    (a) Computational Biology
    (b) Computational Physics
    (c) Computational Chemistry

(d) Applied Mathematics
(e) Electrical/Electronic Engineering
(f) Mechanical Engineering
(g) Medicine
(h) Dentistry
(i) Sports Engineering / Physical Education and Sports
(j) Computer Science / Computer Engineering
(k) Life Sciences
(l) <various alternative programs>

The courses appear under different titles, depending on the focus within the broad field of interest. The frequency analysis is based on generic titles that reflect the core (essence) of the disciplines and needs. For instance, Medical Information Systems, Information Systems and Databases, Information Systems in Healthcare, Biomedical Information Systems, Information Systems in Biomedicine, and similar titles appear more or less for the same content. Medical Information Systems is chosen as generic course title. The same approach is applied for all courses that are identified as similar in content.

At the bachelor level, there is a set of compulsory courses of a fundamental importance, namely mathematics, biology, physics, chemistry, ICT, foreign (English) language, as well as a set of general biomedical courses, such as anatomy, physiology, biochemistry. These are not explicitly shown in the following diagrams and charts. The same holds for placement (internship), project, and final work (thesis).

Syllabi for the same generic title differ, as well. Although naturally overlapped in the contents to the great extent, general classification can be made as follows:

1) general/unified – for all entry qualifications
2) partly general/ unified, i.e. set of compulsory courses and the set of electives (mainly depending on entry qualifications)
    a) pro medical
    b) pro dental
    c) pro engineering
    d) pro biological

Accordingly, BE&MI study programs may have the form of: (a) “pure” BE, (b) “pure” MI, and (c) BE&MI, where “pure” stands for mainly engineering or ICT oriented study programs, with negligible representation of counter field major disciplines. However, the analysis shows that even within the “pure” study programs, specializations provide specific orientations, i.e.

needs of students: engineer, medical doctor, natural scientist, mathematician, ICT engineer, etc. To fulfill essential requirements of BE&MI study program and enable research and innovative dimension, curriculum should contain variety of courses to cover necessary advances in mathematics, engineering and ICT, such as geometrical modeling, data bases and artificial intelligence in medicine, statistics, image processing, as well as advanced disciplines of natural sciences like biochemistry, biophysics, medical optics, measurements, cell biology, etc.

3. Universities

The analysis included 221 European universities, spread over 30 countries. The selection of the universities has been done according to the indices provided by world known ranking studies and portals [39-42] including the Academic Ranking of World Universities and the Leiden Ranking. Not all European universities were analyzed for study programs containing BE&MI related courses. The main lead in universities selection is based on Leiden Ranking list of European universities [40], due to their indicators, but the Shanghai list [39] and search results of portals [41,42] were used for additional selection. Note that Leiden Ranking list contains 214 universities (ranking 2013), where not all of them offer BE&MI related study programs. The results include 94 Leiden ranked universities. The distribution of analyzed universities is shown in Figure 1.

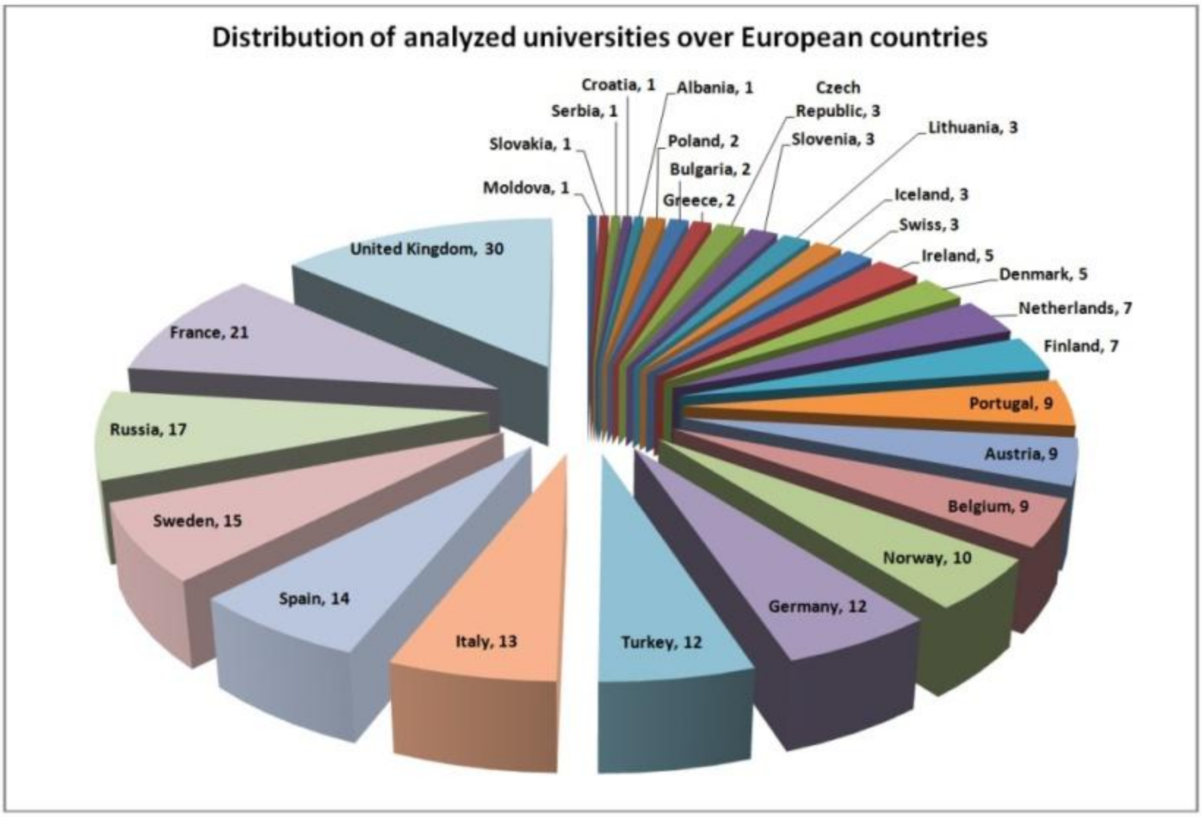

Figure 1. Distribution of analyzed European universities

4. Biomedical Technology

Overall analysis tends to comprehend broad field of BE&MI from different aspects, respecting basic definitions of the constituent subfields. In its widest meaning the field of BE&MI stems from the global field of Biomedical Technology (Figure 2). It should be noted that in some publications Biomedical Technology and Bioengineering are used interchangeably, lacking, in general, establishment of clear boundaries.

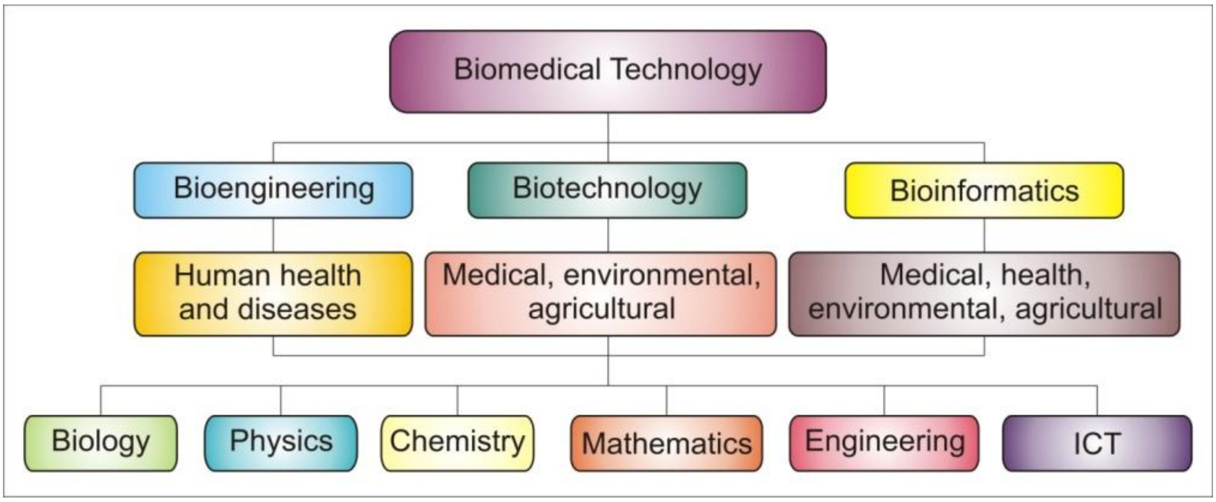

Figure 2. Global field of Biomedical Technology

Three major subfields are bioengineering, biotechnology, and bioinformatics. All three span almost over complete biomedical and health issues of living organisms, including humans, animals, flora, and environment. Fundamental principles, approaches, methodologies, and technology are interlaced and converging in numerous distinct application domains. Bioengineering is broader discipline than often interchanging concept of Biomedical engineering. According to the definitions given in Encyclopedia of Agricultural, Food, and Biological Engineering [43] and the National Institutes of Health [44], Bioengineering or Biological Engineering (including biological systems engineering) is the application of concepts and methods of biology (and secondarily of physics, chemistry, mathematics, and computer science) to solve real-world problems related to the life sciences and/or the application thereof, using engineering's own analytical and synthetic methodologies and also its traditional sensitivity to the cost and practicality of the solution(s) arrived at. Or, Bioengineering is the application of experimental and analytical techniques based on the engineering sciences to the development of biologics, materials, devices, implants, processes and systems that advance biology and medicine and improve medical practice and health care. On the other side, Biomedical engineering is a discipline that advances knowledge in engineering, biology and medicine, and improves human health through cross-disciplinary activities that integrate the engineering sciences with the biomedical sciences and clinical practice. It includes: (a) the acquisition of new knowledge and understanding of living systems through the innovative and substantive application of experimental and analytical techniques based on the engineering sciences, and (b) the development of new devices, algorithms, processes and systems that advance biology and medicine and improve medical practice and health care delivery [45]. Casual distinction could be made in the terms that bioengineering is oriented towards health and diseases issues of all living organisms, while biomedical engineering focuses more towards corresponding issues of the humans.

Biotechnology is a vast field of science, and hence difficult to concisely define. Nevertheless, for the purpose of this review definition presented in Merriam-Webster's Medical Dictionary [46] reflects the complexity of the field concerned with medicine, health, environment, and agriculture: Biotechnology is the body of knowledge related to the use of organisms, cells or cell-derived constituents for the purpose of developing products which are technically, scientifically and clinically useful; alteration of biologic function at the molecular level (i.e., genetic engineering) is a central focus. It is further divided into three main parts: (a) green biotechnology – agricultural processes, (b) red biotechnology – related to the health care processes, and (c) white biotechnology – related to the industrial and environmental processes [47].

Bioinformatics in its narrow, original and straight forward sense is focused on creating and analyzing datasets of macromolecular structures, genome sequences, and the functional genomics, which combines elements of biology and computer science. Accordingly, (molecular) bioinformatics is defined as “conceptualizing biology in terms of molecules (in the sense of Physical Chemistry) and applying “informatics techniques” (derived from disciplines such as applied maths, computer science and statistics) to understand and organize the information associated with these molecules, on a large scale. In short, bioinformatics is a management information system for molecular biology and has many practical applications” [48]. In addition, bioinformatics, although distinctive and independent discipline, is quite often accepted in much broader sense of Biomedical Informatics or Medical (Health) Informatics, which in turn is also considered as different and independent discipline. Following the National Institutes of Health definition, bioinformatics focuses on “research, development, or application of computational tools and approaches for expanding the use of biological, medical, behavioral or health data, including those to acquire, store, organize, archive, analyze, or visualize such data” [49]. That is, “the field that concerns itself with the cognitive, information processing, and communication tasks of medical practice, education, and research, including the information science and the technology to support these tasks..., and deals with biomedical information, data and knowledge – their storage, retrieval and optimal use for problem solving and decision making” [50].

All these definitions clearly emphasize fundamentals rooted in science, i.e. biology, chemistry, physics, mathematics, as well as engineering and ubiquitous ICT. Understanding BE&MI as the converging synthesis of medicine and life sciences, engineering, and technology (Figure 3) directs curriculum development towards balanced mixture of courses that will support integration of converging and enabling disciplines to meet the aforementioned challenges of education, research, and innovation.

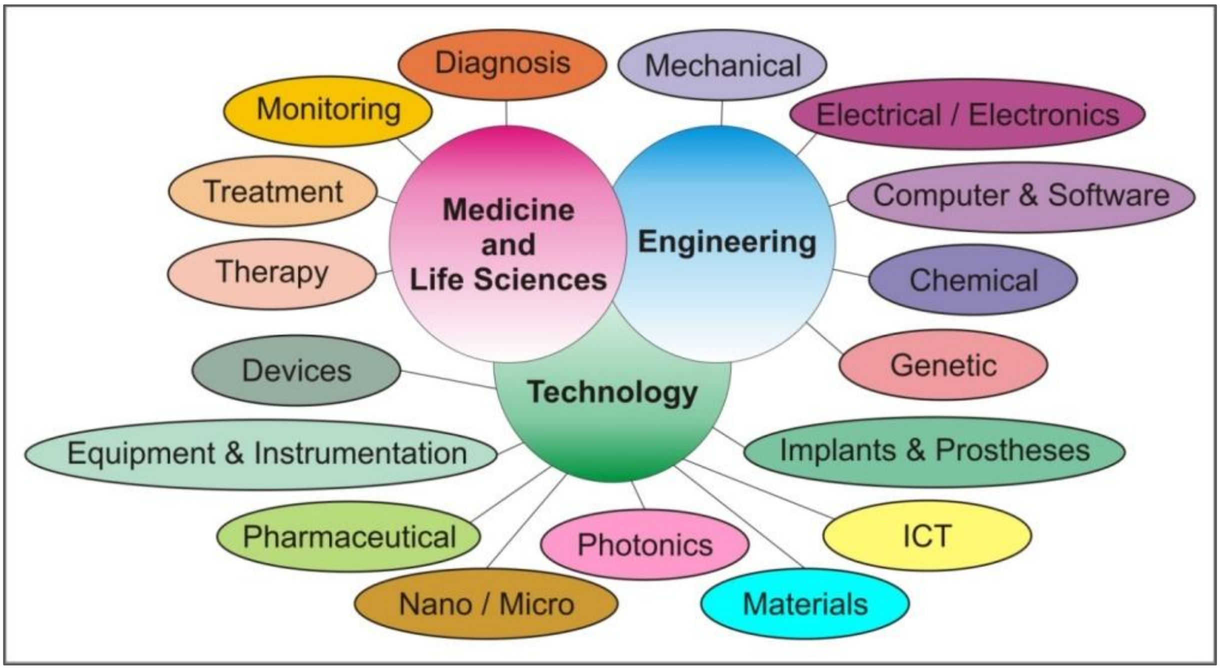

Figure 3. Synthesis of Medicine and Life Sciences, Engineering, and Technology

EU and other European universities have the rich experience, good practice and yet evolving approaches in educating professionals of BE&MI. The following generic sets of courses at bachelor and master levels present state of the art in BE&MI study programs offer, with an emphasis on curriculum of Medical Informatics.

5. Curriculum in Medical (Health) Informatics

The synthesis of engineering, medical, and biological systems generates different forms of curricula, depending on the major field of interest and application. Rough classification into general BE&MI, "pure" BE, and "pure" MI classes is merely conditional. However, the analysis shows that "pure" MI study programs are significantly present at European universities, although less than general BE&MI and "pure" BE study programs. The following analysis is based on the generic titles of the courses, due to huge variety of alternatives. Compulsory fundamental science, humanities, and literacy courses are not explicitly shown.

"Pure" MI study programs offer relatively small selection of courses. The main reason is the nature of ICT disciplines and overall involvement in the field of biomedical science, although significance and intensity are more than obvious. At the bachelor level there are only 6 generic courses directly oriented towards biomedical applications, namely (Figure 4) [51]:

1. Health Services Management and Policy
2. Introduction to Bioinformatics
3. Health Information Systems
4. Medical Data Bases / EHR
5. Data Structures and Algorithms
6. Introduction to Scientific/Biomedical Programming.

These core generic courses are almost evenly distributed among European MI curricula, making them the essential for the MI professionals. Common three years bachelor level curricula provide just the basics for future professionals aiming at working in an interdisciplinary environment. Such education prepares the ITC professionals in two ways: to directly engage with public health and hospital/clinical information services, and to proceed to the next levels of education.

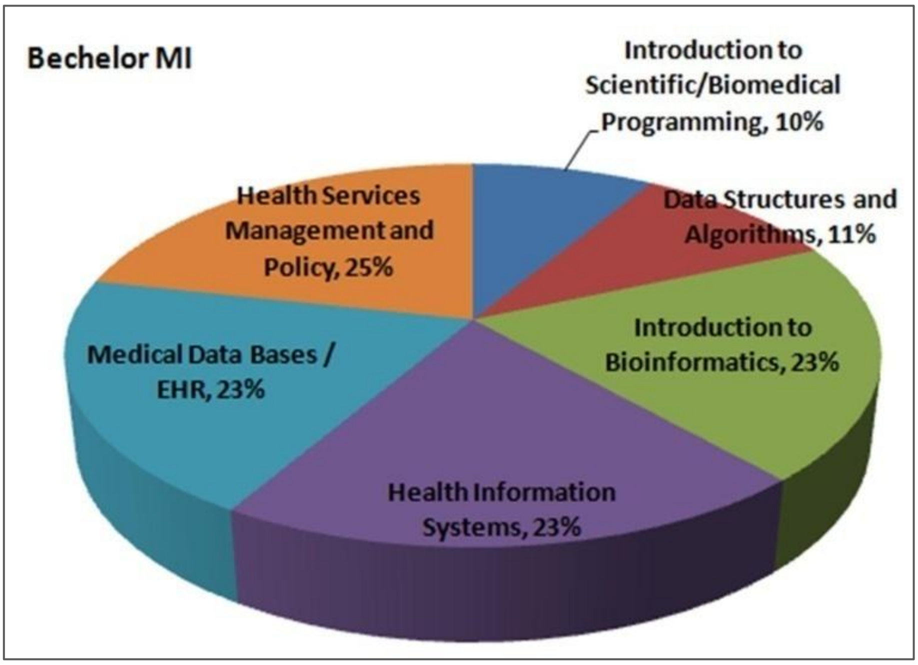

Figure 4. Distribution of MI bachelor courses at European universities

The set of generic MI courses at master level covers advanced knowledge innovative disciplines. There are 14 courses in total (Figure 5):

1. Bioinformatics
2. Geometrical Modeling (in Medicine)
3. Navigation and Robotic Systems in Medicine / Computer Aided Medical Procedures / Computer Assisted Surgery;
4. Biomedical Statistics

5. Biomedical Data Analysis and Processing
6. Medical Information Systems
7. Computer Graphics (in Medicine)
8. Artificial Intelligence in Medicine
9. Computer Aided Diagnosis
10. E-learning in Medicine
11. Programming in the Biomedical Engineering
12. Augmented Reality in Medicine
13. Telemedicine
14. E-health.

One should note that 0% frequency for E-health and Telemedicine courses means actually "less than 1%". These courses are taught as separates disciplines at some universities. Same courses are quite often included as topics within more common courses like Medical Information Systems and Computer Aided Diagnosis for the former two, and Geometrical Modeling (in Medicine), Navigation and Robotic Systems in Medicine / Computer Aided Medical Procedures / Computer Assisted Surgery, Computer Aided Diagnosis for the latter.

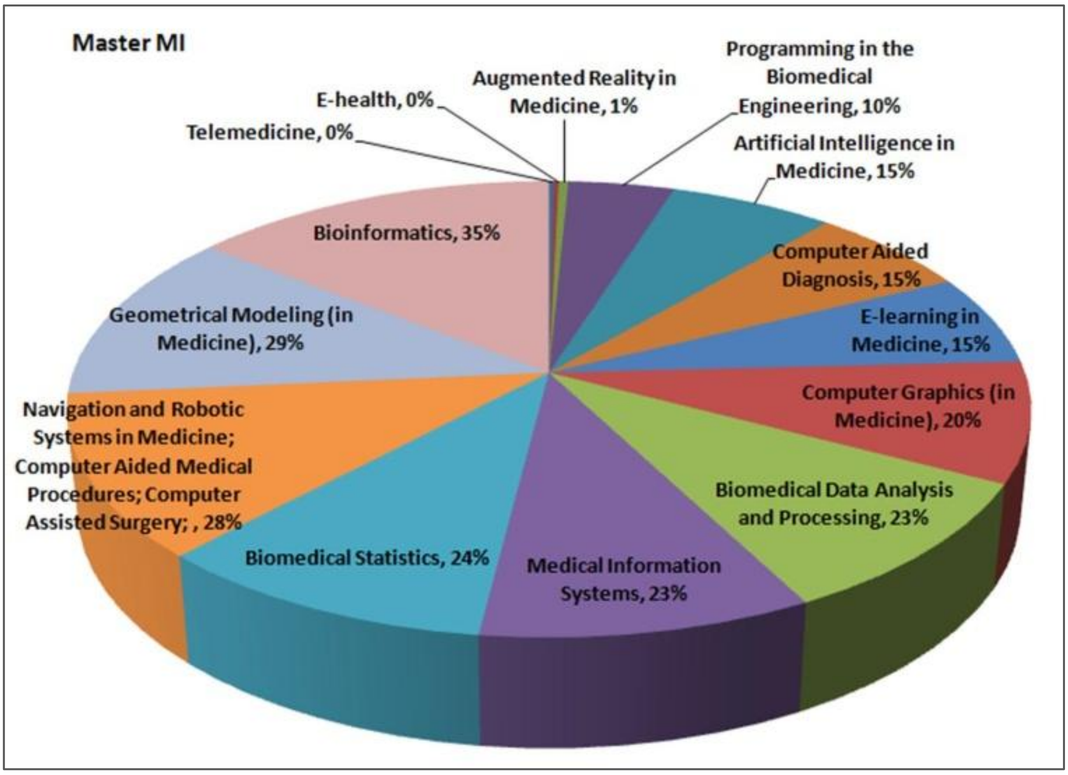

Figure 5. Distribution of MI master courses at European universities

Larger diversity of courses offered at master level implies not only the need for more advanced knowledge and specialization, but also preparation for further research work at doctoral level. This offer is the reflection of the main axes of development within key European strategies of research and innovation.

International Standard Classification of Occupations [22] classifies biomedical engineers in the professionals’ Unit Group 2149: Engineering Professionals not elsewhere classified. On the other side, explicit classification for medical (health) ICT specialists does not exist. This implies that they are generally classified in professional’s Sub-major Group 25: Information and Communications Technology Professionals, and consequently in Unit Group 25x9: <Information and Communications Technology Professionals> not elsewhere classified. However, market analyses reports that job opportunities for MI professionals show an unprecedented demand in the last few years [53]. Availability and utilization of ICT products forced, especially during last decade, public health and clinical workforce to change the way they acquire, store, retrieve, and use medical and health data and information. Proper support of specialized ICT professionals and clinical engineers become the inevitable for coping with expectations and overall progress. Unfortunately, in the WB countries there are no specific regulation and legislative in the area of BE&MI. Tempus project BioEMIS tends to create the links at the educational and professional level.

6. Conclusions

Analysis of study programs offered at 221 European universities has yielded basic guidelines for study programs development at the different levels at WB universities. These guidelines, as well as standards and recommendations, will be used at WB universities to transfer “know-how” from the EU and other European universities. This information will be used to introduce 4 PhD programs and modernize one in BE&MI (3 years, 180ECTS), introduce 5 M.Sc. programs and modernize one (2 years, 60ECTS), and introduce 3 specializations (1 year, 30ECTS).

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